

CDF Luminosity Studies

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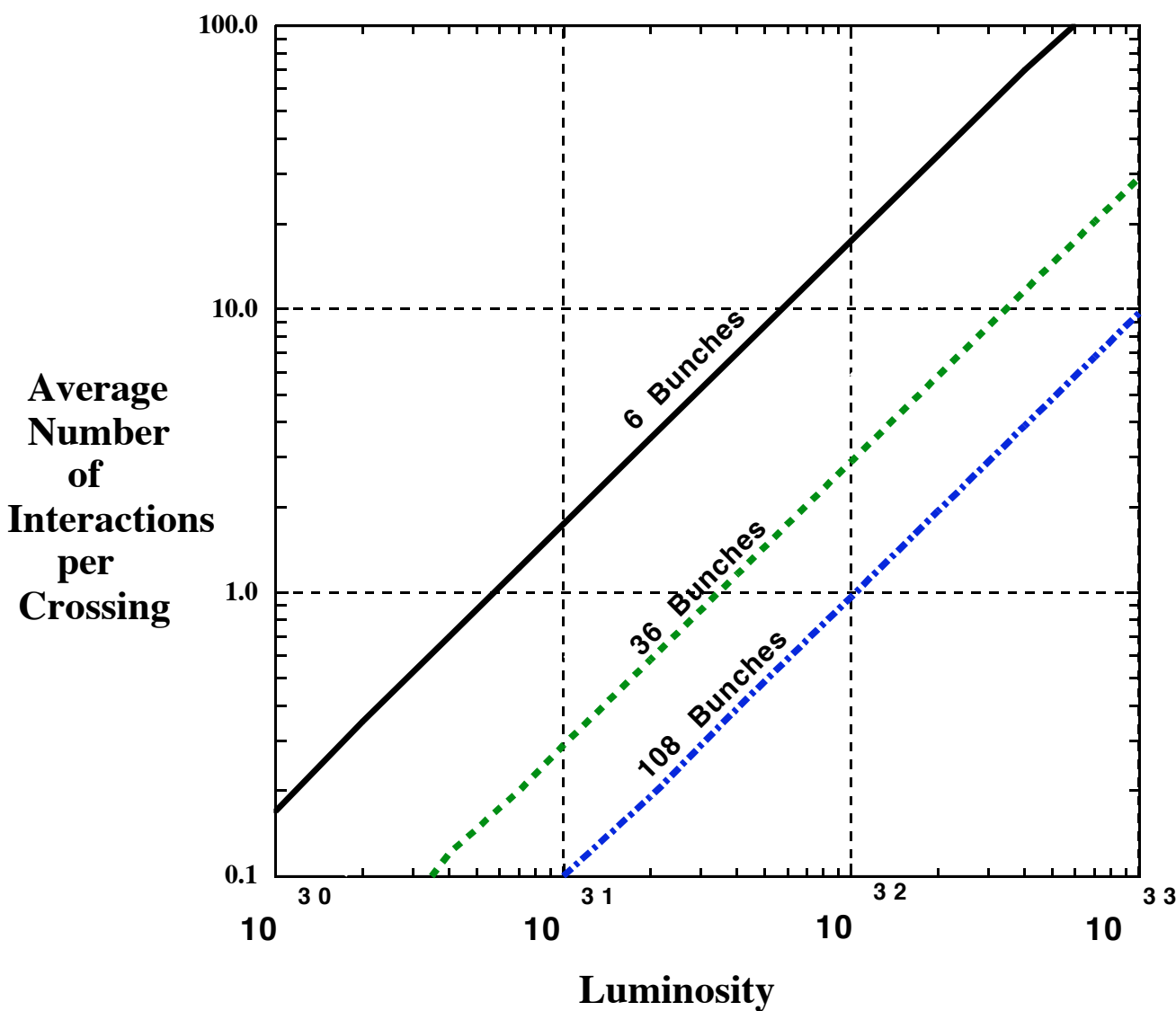
on behalf of the CDF Luminosity group

Fermilab All Experimenter's Meeting

Specifications for CDF Luminosity Detector

- Precise absolute measurement of total luminosity is crucial for physics
- Rate of ppbar interactions

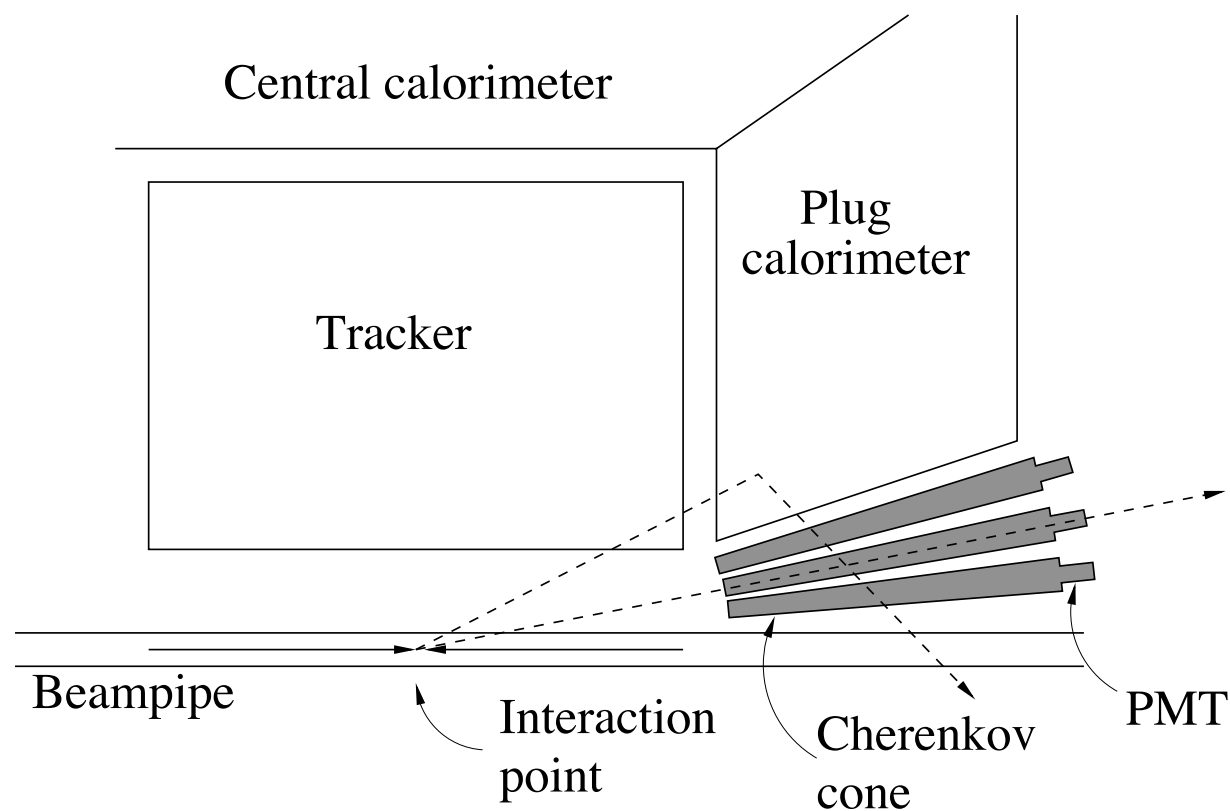
$$N_{pp} = \mu f_{BC} = \sigma_{in} L$$
- Operate at high luminosity ($L \sim 4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, $\mu \sim 12 \text{ ppbar/BC}$)



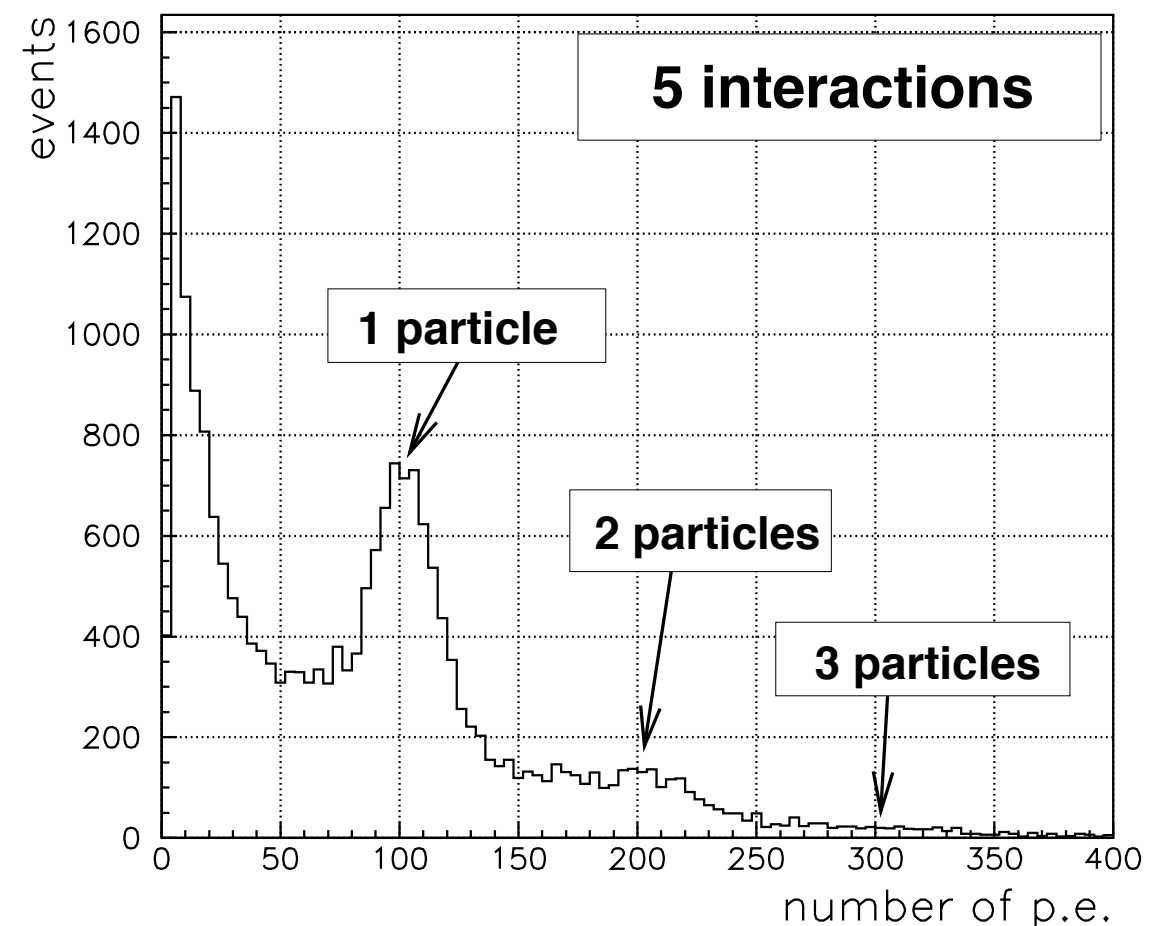
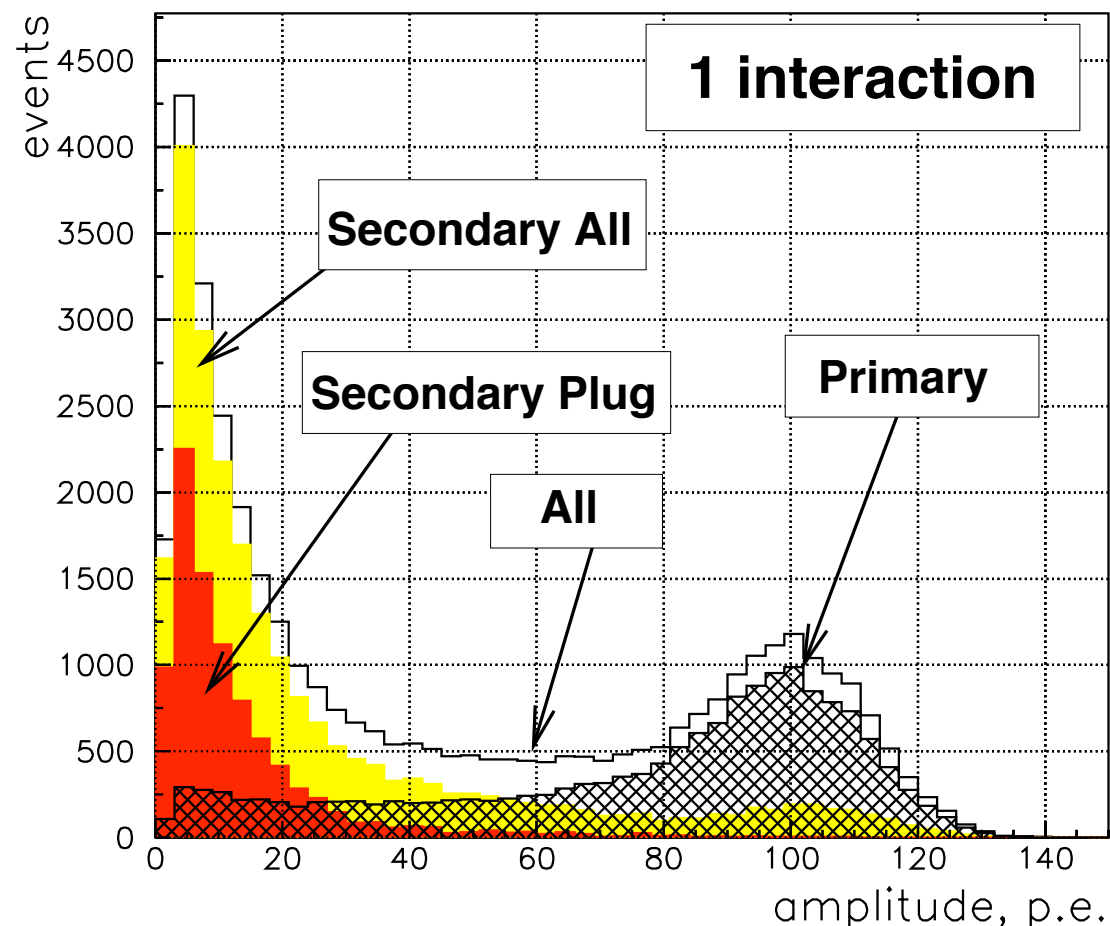
- Measure Luminosity
 - Instantaneous and Total
 - Real-time
 - Bunch by bunch
 - Precise (few %)
- Z-profile of collisions
- Provide Minimum Bias Trigger

CDF: Gaseous Cherenkov Luminosity Counters

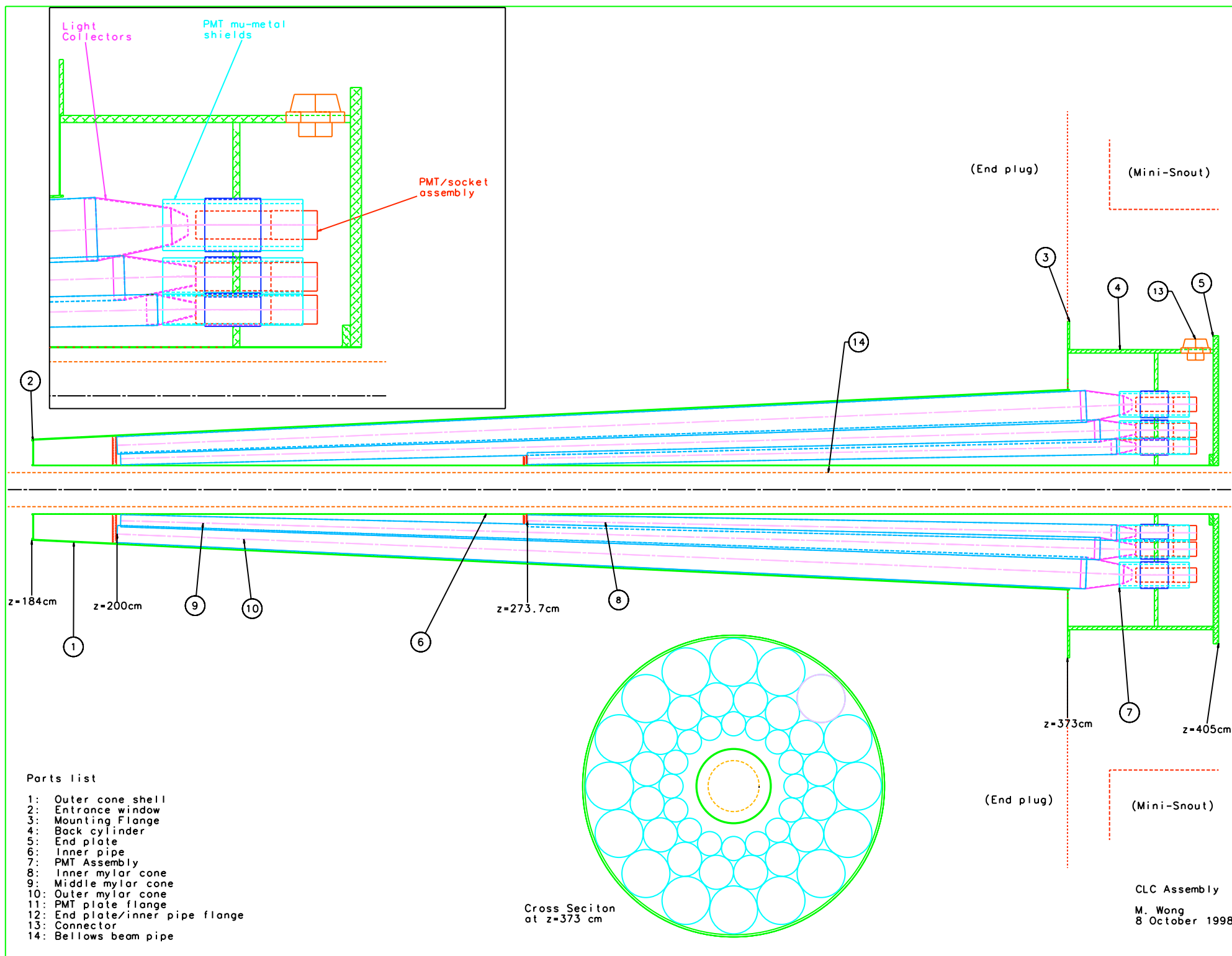
Cherenkov Luminosity Counters: Basic Ideas



- Separate particle from primary interactions and sec. particles
- Good amplitude resolution
 - ▶ about 18% (photo stat, light collection, PMT resolution)
- Good timing resolution
 - ▶ separate collisions/losses
- Radiation hard, low mass



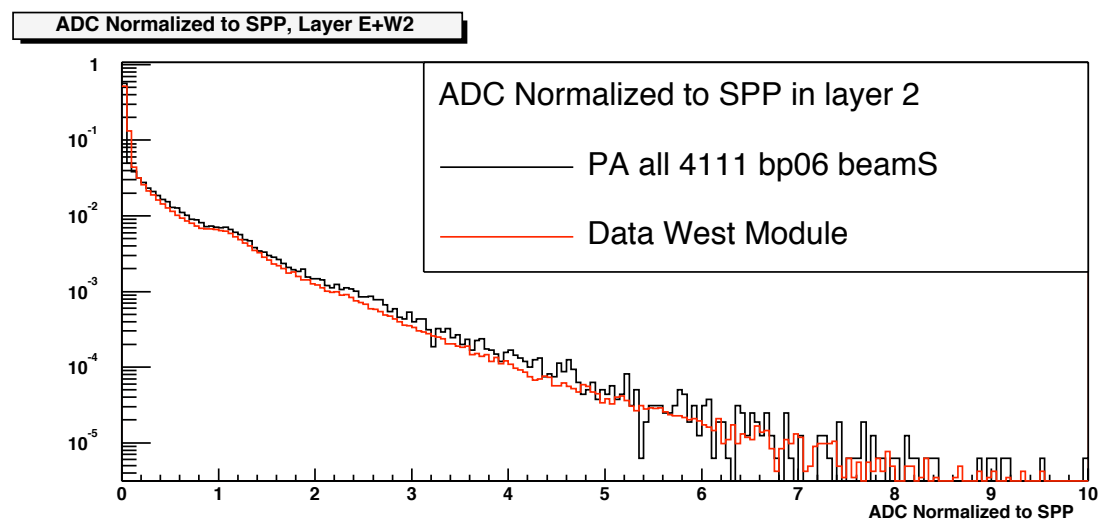
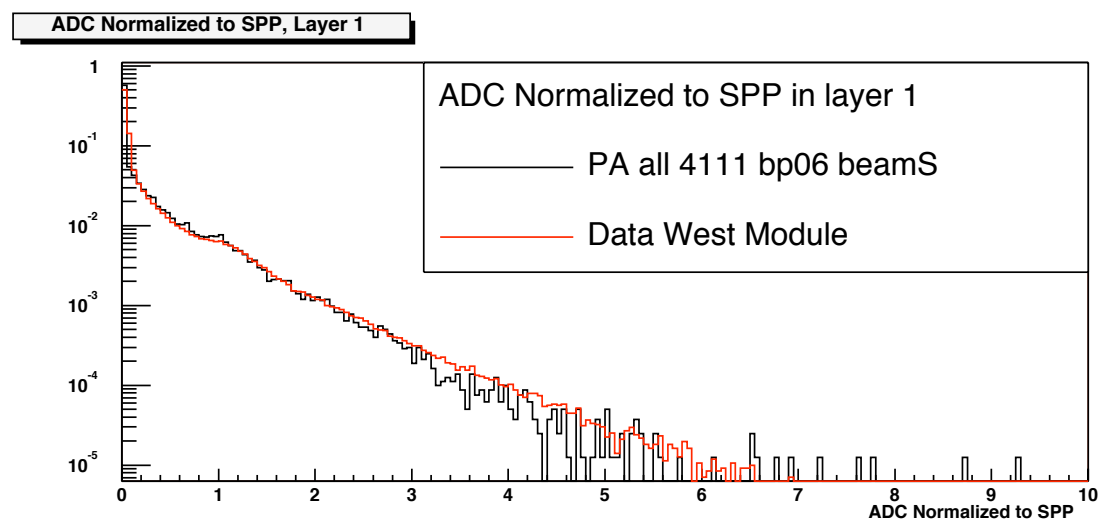
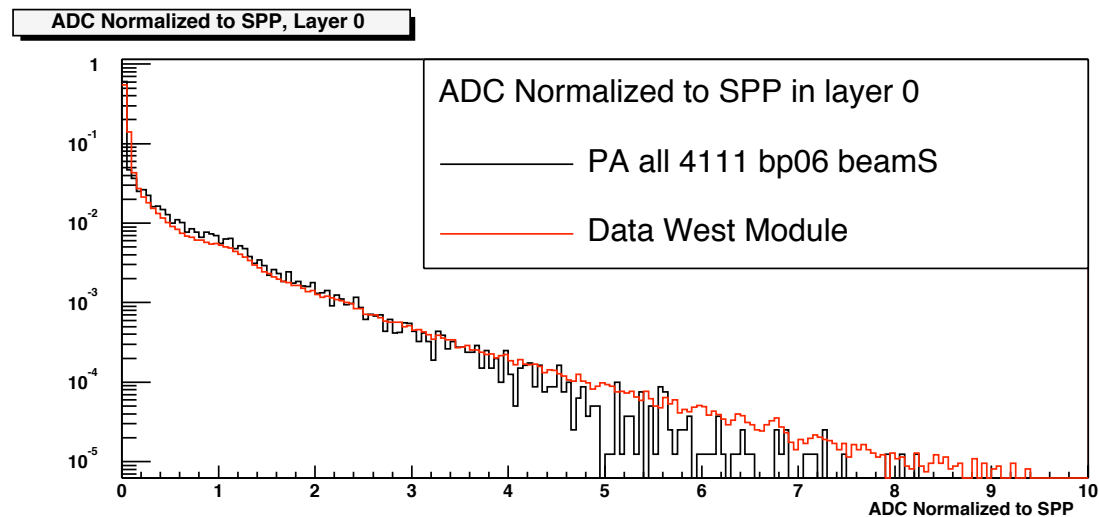
Cherenkov Luminosity Counters: Design



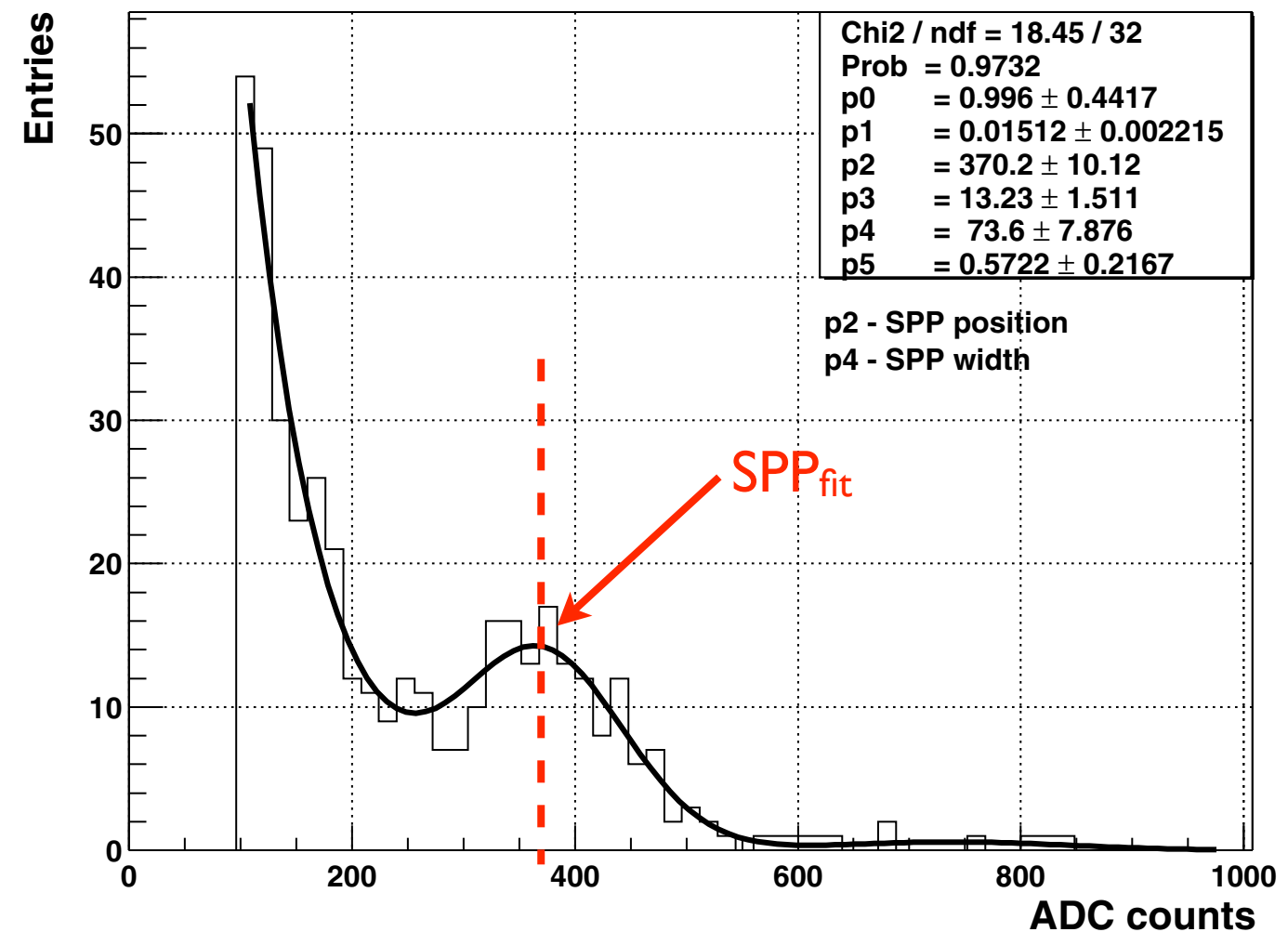
- 48 counters/side
- 3 layers × 16 counters
- Coverage: $3.7 \leq |\eta| \leq 4.7$
- Isobutane 2 atm, $n = 1.000143$, $\theta_c = 3.1^\circ$
- PMT Hamamatsu R5800Q CC quartz window, gain 10^5

Amplitude Distributions in ppbar Collisions

• Full Simulation vs Data

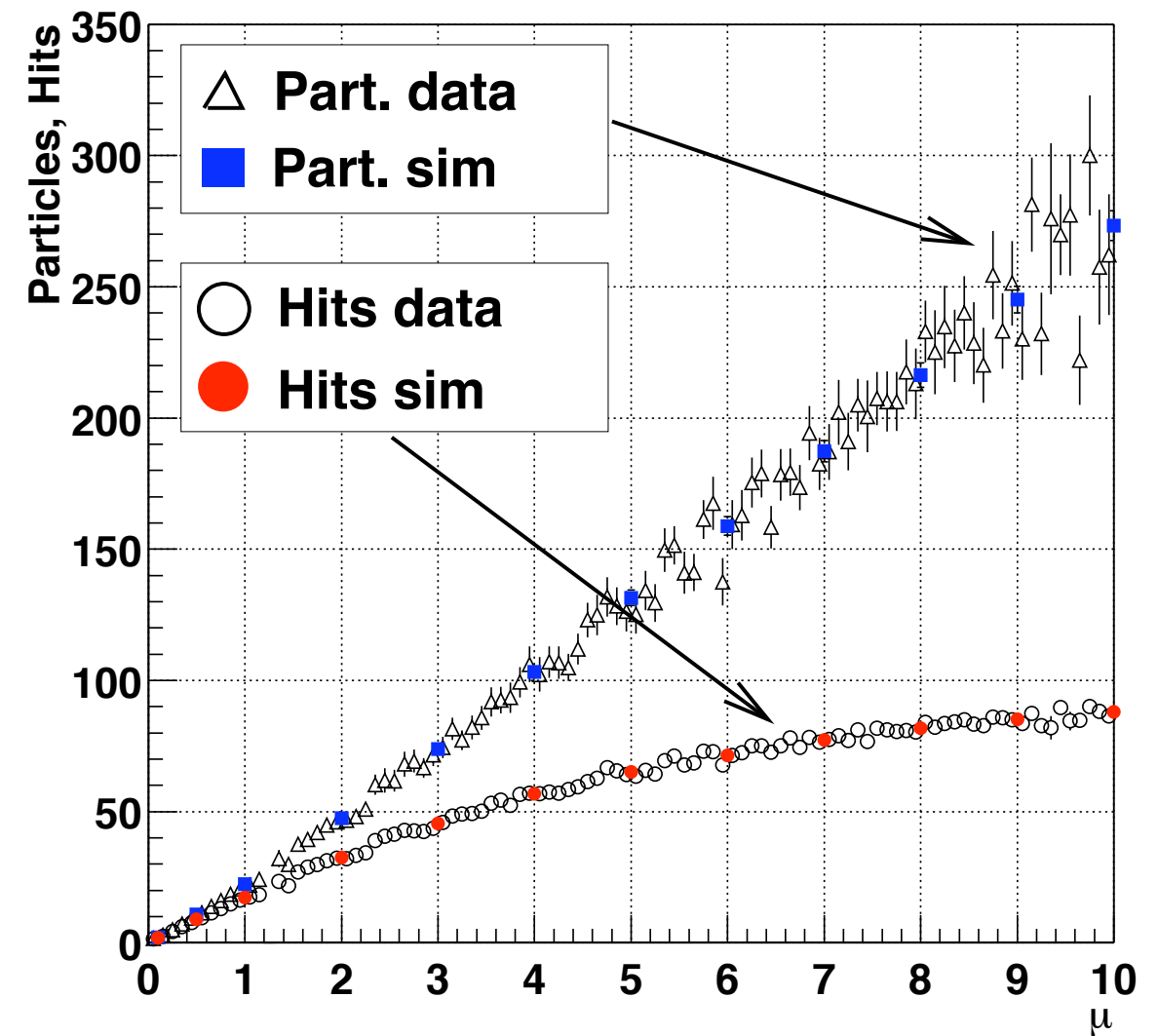
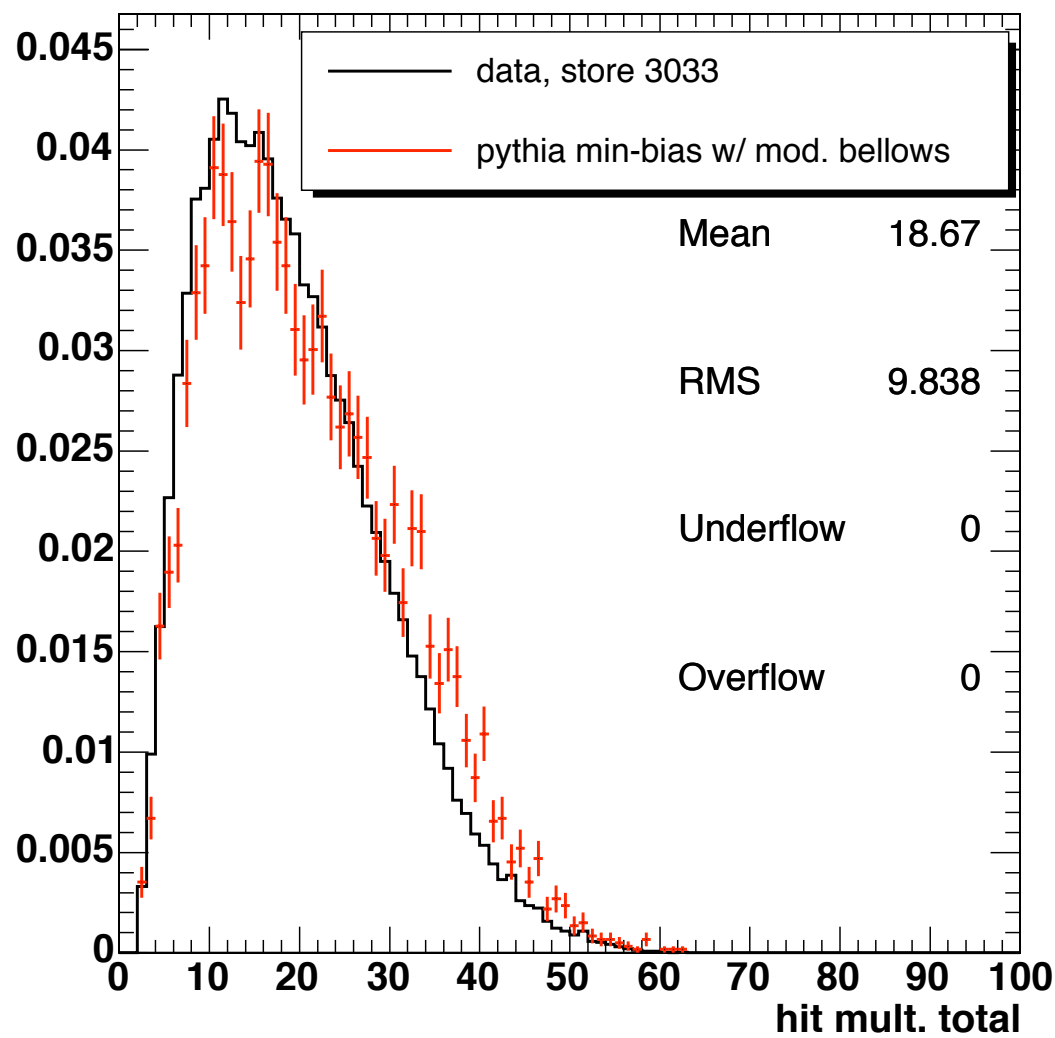


- Simulation agrees well w/ data
- Single particle peak buried under secondary interactions
- **Clear peak** after isolation requirement:
 - ▶ Amplitude < 20 p.e. in surrounding counters



Multiplicity Distributions in ppbar Collisions

- Hits: counters with Amplitude > threshold (250 ADC, set in firmware)
- Particles: $N_{\text{part}} = \text{Amplitude} / \text{Amplitude}_{\text{SPP}}$



- Shape of multiplicity is more sensitive to variations in PMT gain (data) and accounting for all material in front of the detector (simulation)

Good agreement between data and simulation for average multiplicities

Luminosity Measurement Basics

- Rate of ppbar interactions:
 $N_{pp} = \mu f_{BC} = \sigma_{in} L$, where
 - ▶ f_{BC} is freq. of bunch crossings
 - ▶ $\sigma_{in}=61.7$ mb is x-sec. of pp int.
 - ▶ μ is number of int./BC

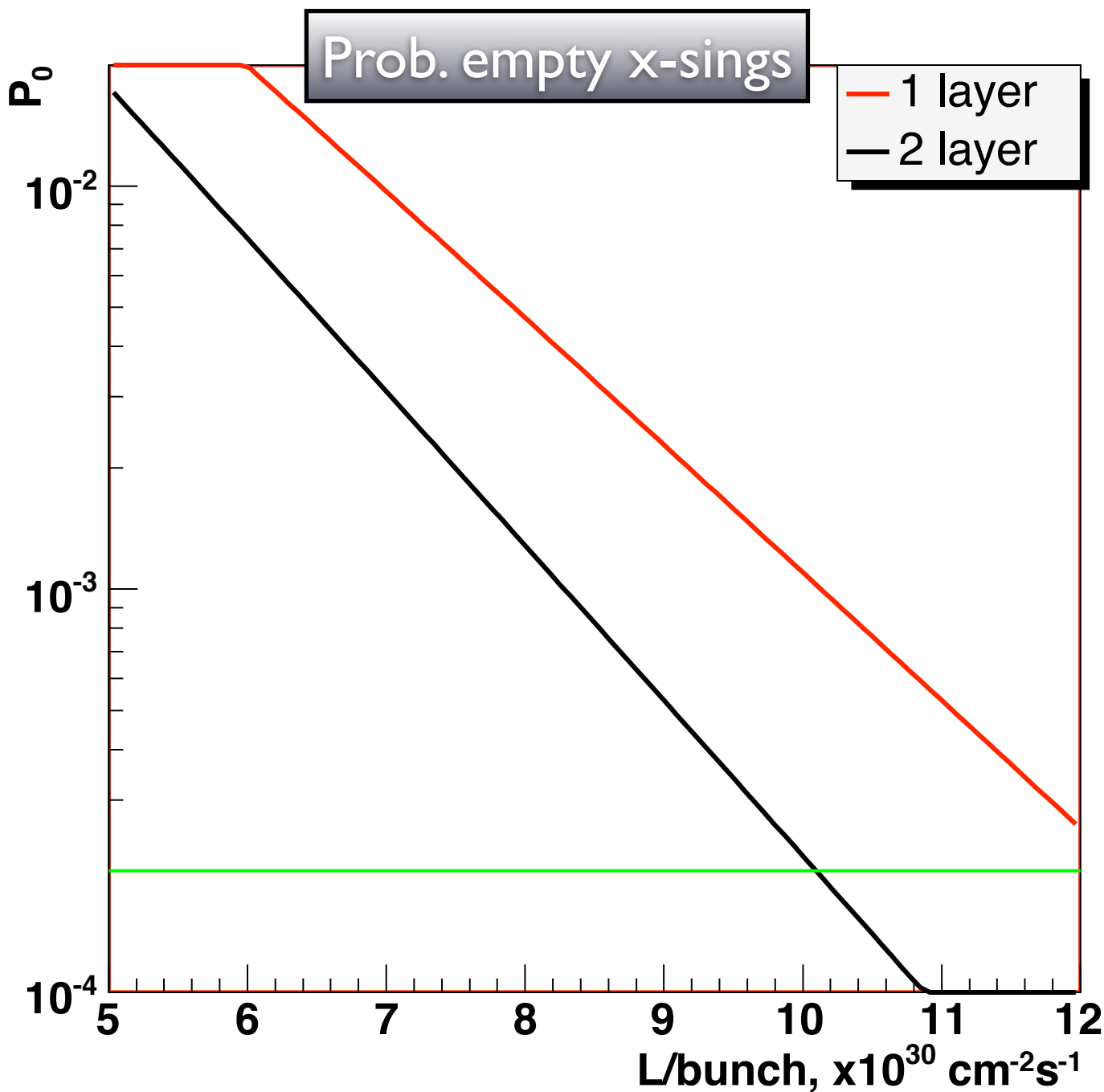
- Instantaneous Luminosity

$$L = \mu f_{BC} / \sigma_{in}$$

- How to measure μ ?

- Empty Crossings: BC w/o int.
 - ▶ probability: $P_0 = N_0 / N_{BC}$
 - ▶ naively: $P_0 = e^{-\mu} \Rightarrow \mu = -\log P_0$
 - ▶ need to take into account detector acceptance:
 $P_0 = (2e^{\mu \epsilon_I} - 1) \cdot e^{-\mu(1-\epsilon_0)}$
where ϵ_0 is prob. of no hits in detector and ϵ_I is prob. of hits only in one side
 - ▶ systematic uncertainty 4.5%
 - dominated by acceptance (4%)
- Other methods:
 - ▶ Hits: $\mu = N_{BC}^{hits} / N_I^{hits}$
 - ▶ Particles: $\mu \sim \sum_i A_i$

High Luminosity: Rare Empty Crossings

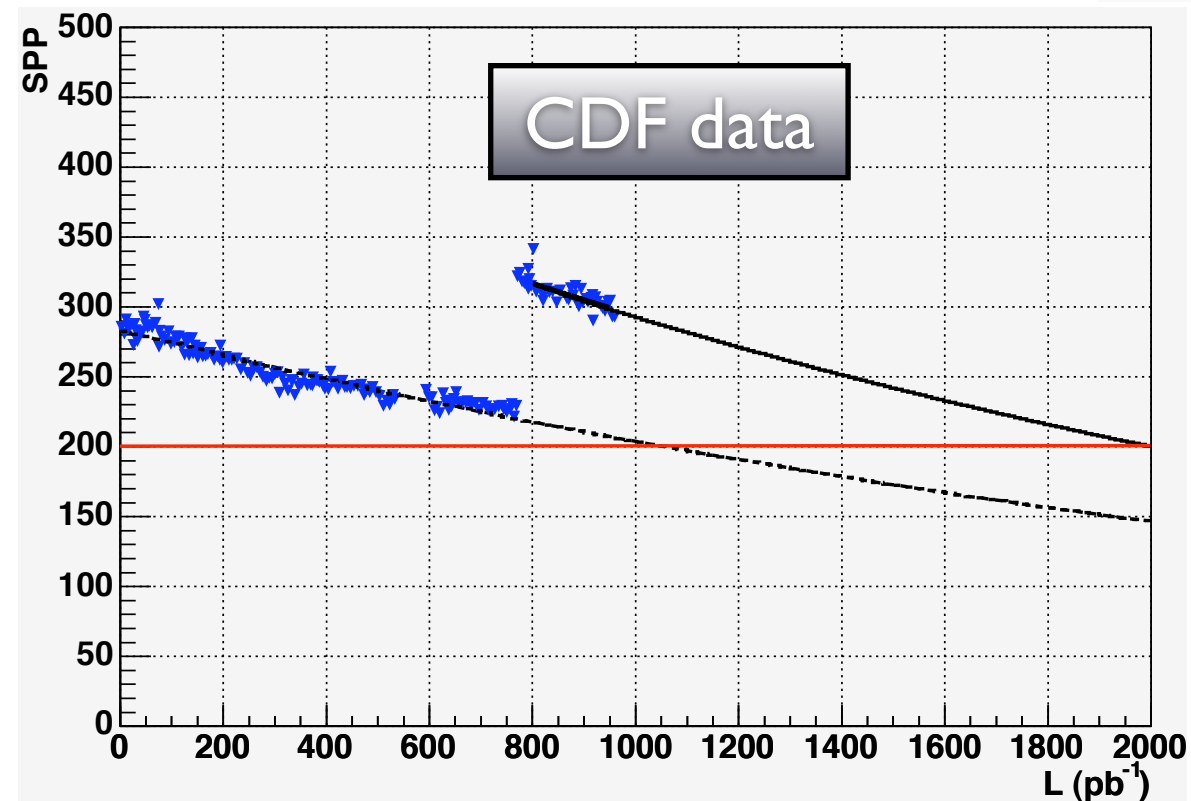
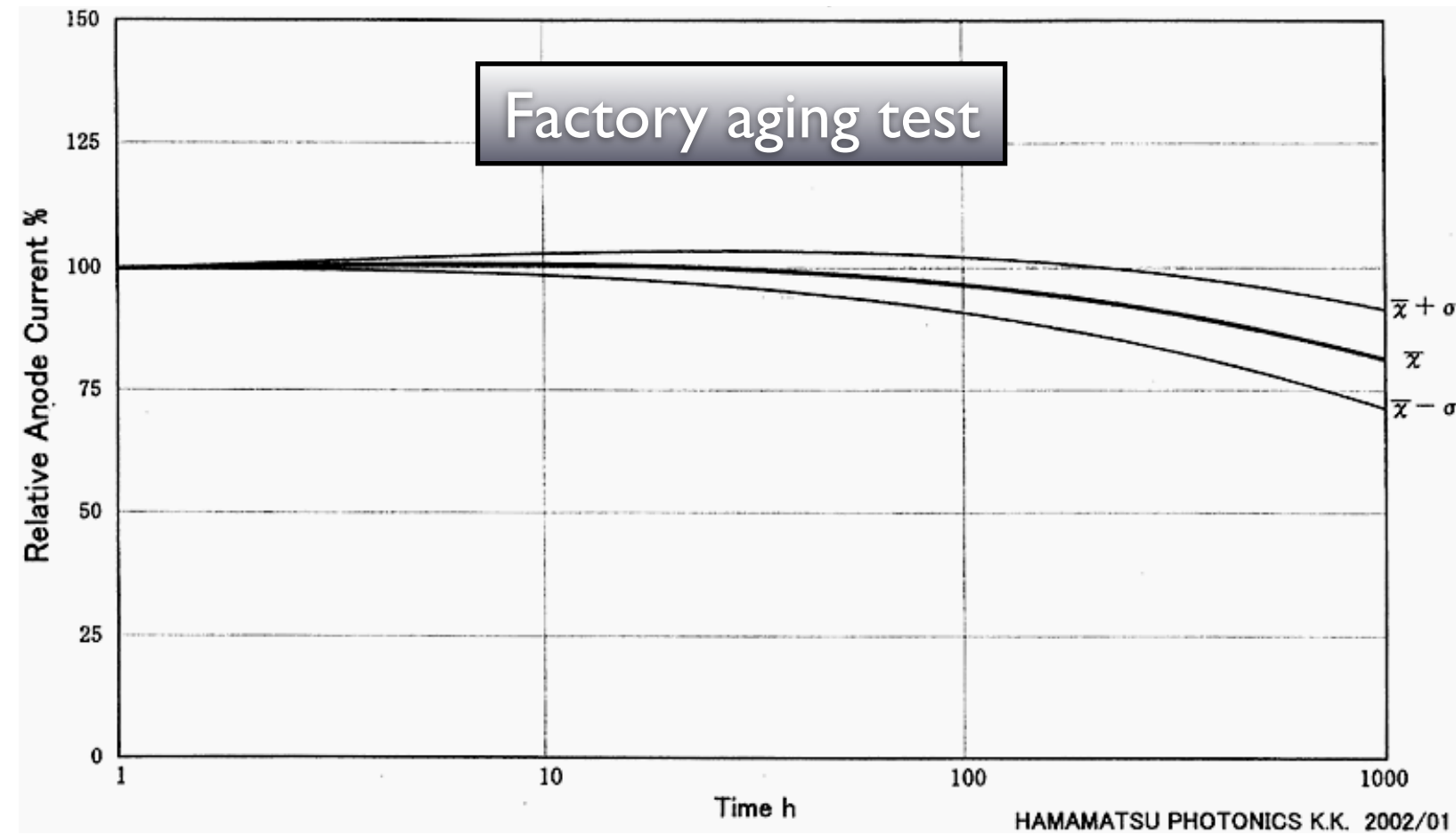


- Typical acceptances
 - ▶ 2 Layers: $\epsilon_0 \sim \epsilon_1 \sim 15\%$, $\text{acc} \sim 55\%$
 - ▶ 1 Layer: $\epsilon_0 \sim \epsilon_1 \sim 20\%$, $\text{acc} \sim 40\%$
- $N_{\text{BC}} \approx 20000$ per measurement
 - ▶ limited by h/w DAQ
- Cutoff (adjustable in s/w)
 - ▶ $N_0 < 4$, $P_0 < 2 \cdot 10^{-4}$
- Cutoff Luminosity (assuming equal luminosity per bunch)
 - ▶ using 2 Layers: $\sim 360 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$
 - ▶ using 1 Layer: $\sim 400 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$

Reliable Luminosity measurements up to $L \sim 400 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$

Large Total Luminosity: Aging

- Factory aging test
 - ▶ 1000 h at 10 μA
 - ▶ $\Delta I / I = 10 - 35\%$
- Corresponds to 30 - 80 % per fb^{-1}

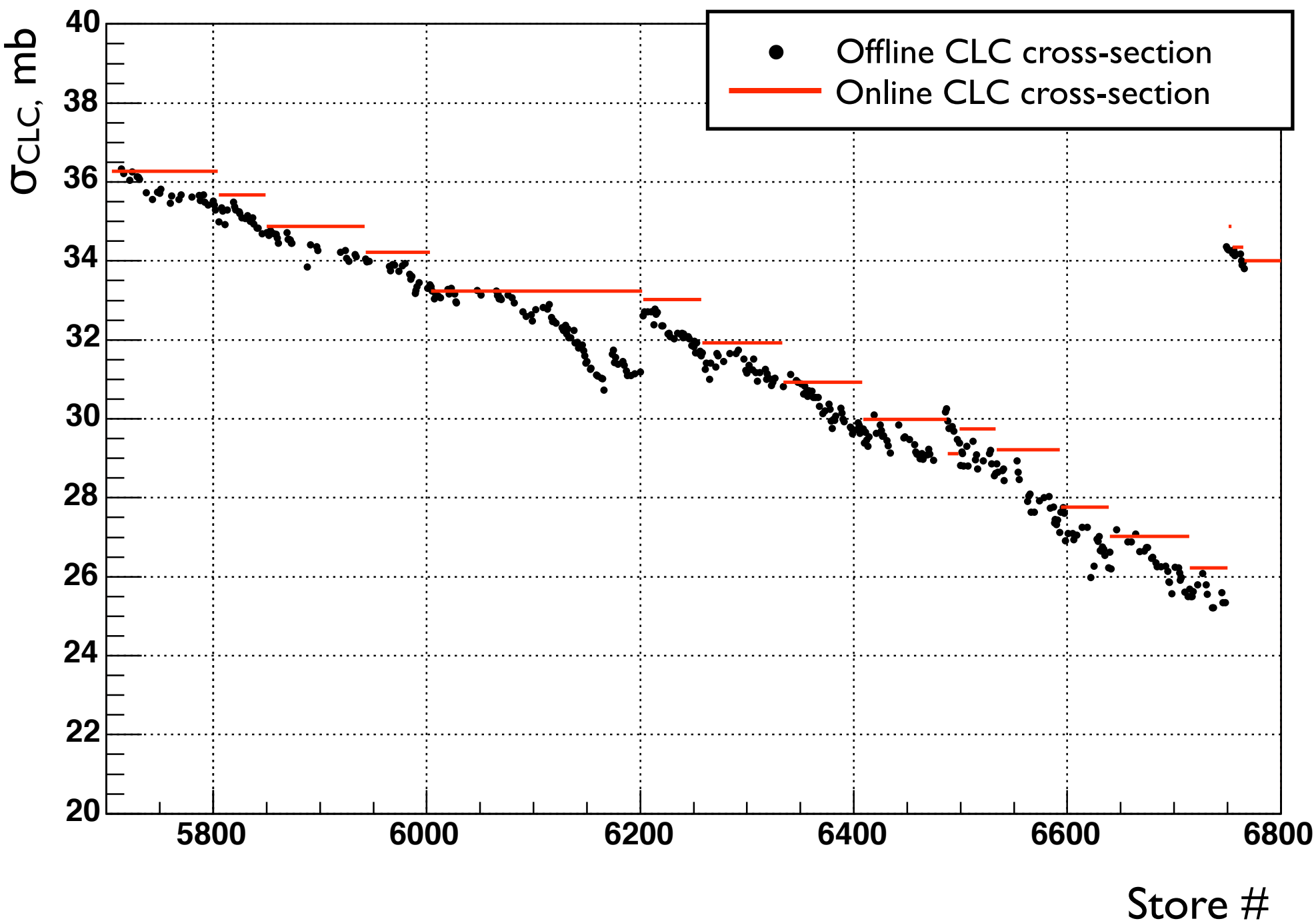


- PMT aging in detector
 - ▶ hard to calibrate Ampl. < 200
 - ▶ aging rate aprox. 35% per fb^{-1}
 - ▶ agrees well w/ Hamamatsy spec.
- HV/gain adjustments:
 - ▶ same aging rate

Survive few fb^{-1}

CLC Effective Cross-section

- CLC cross-section vs store # (after 2007 shutdown)



In situ calibrations

- Use real data
- Fit SPP
- Feed SPP values to Monte-Carlo simulation
- Get new effective CLC cross-section
- Adjust online
- Apply offline corrections

Offline corrections applied for every store: Physics is not affected

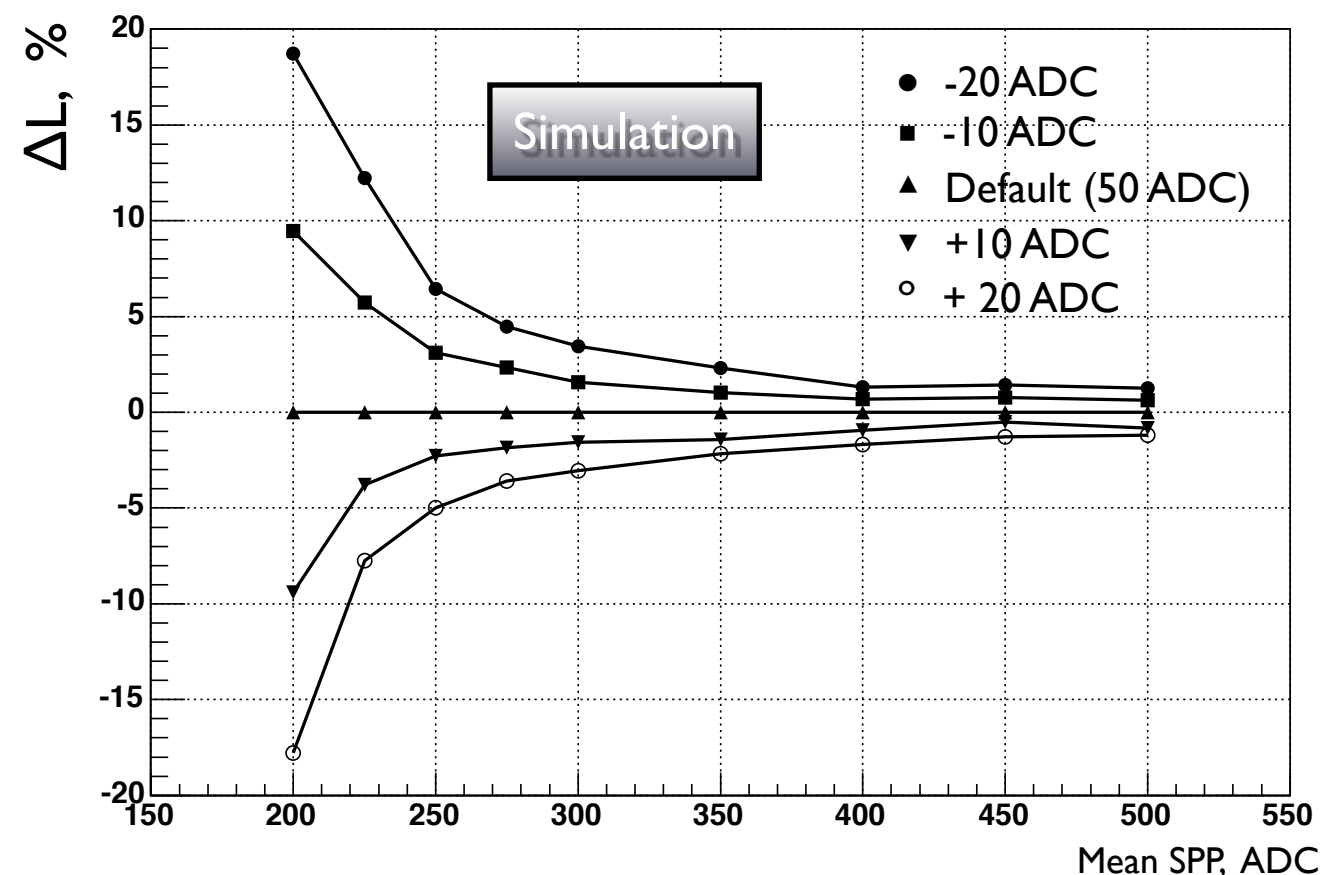
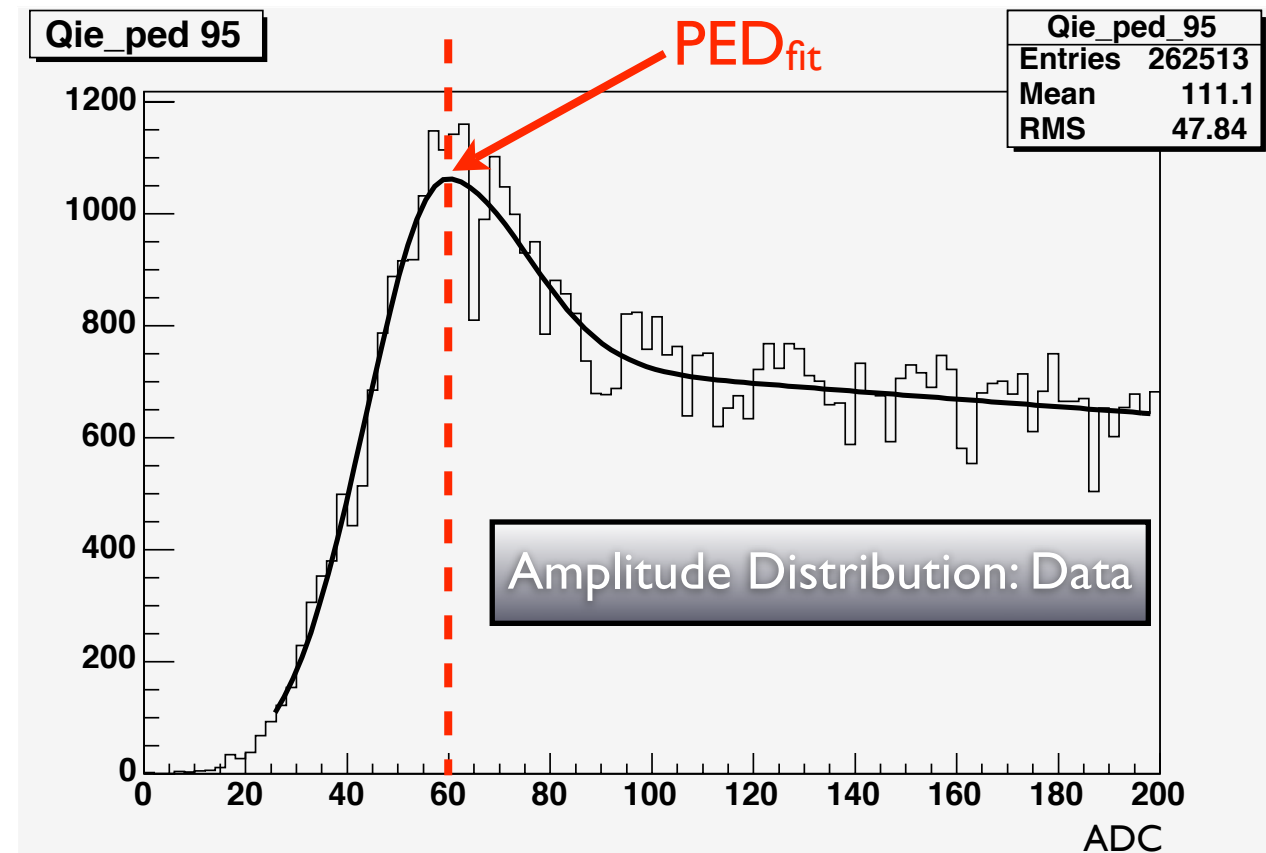
Pedestal Effect on Luminosity Measurement

- SPP_{fit} and PED_{fit} are obtained from data
- Acceptances are calculated using Monte-Carlo simulation
- SPP are corrected for pedestal and then we add default constant term of 50 ADC:

$$SPP_{acc} = SPP_{fit} - PED_{fit} + 50$$

- Method is fine for PMTs working at high gain. As PMTs age and gain drops, effect of deviation of pedestals from default value become more evident

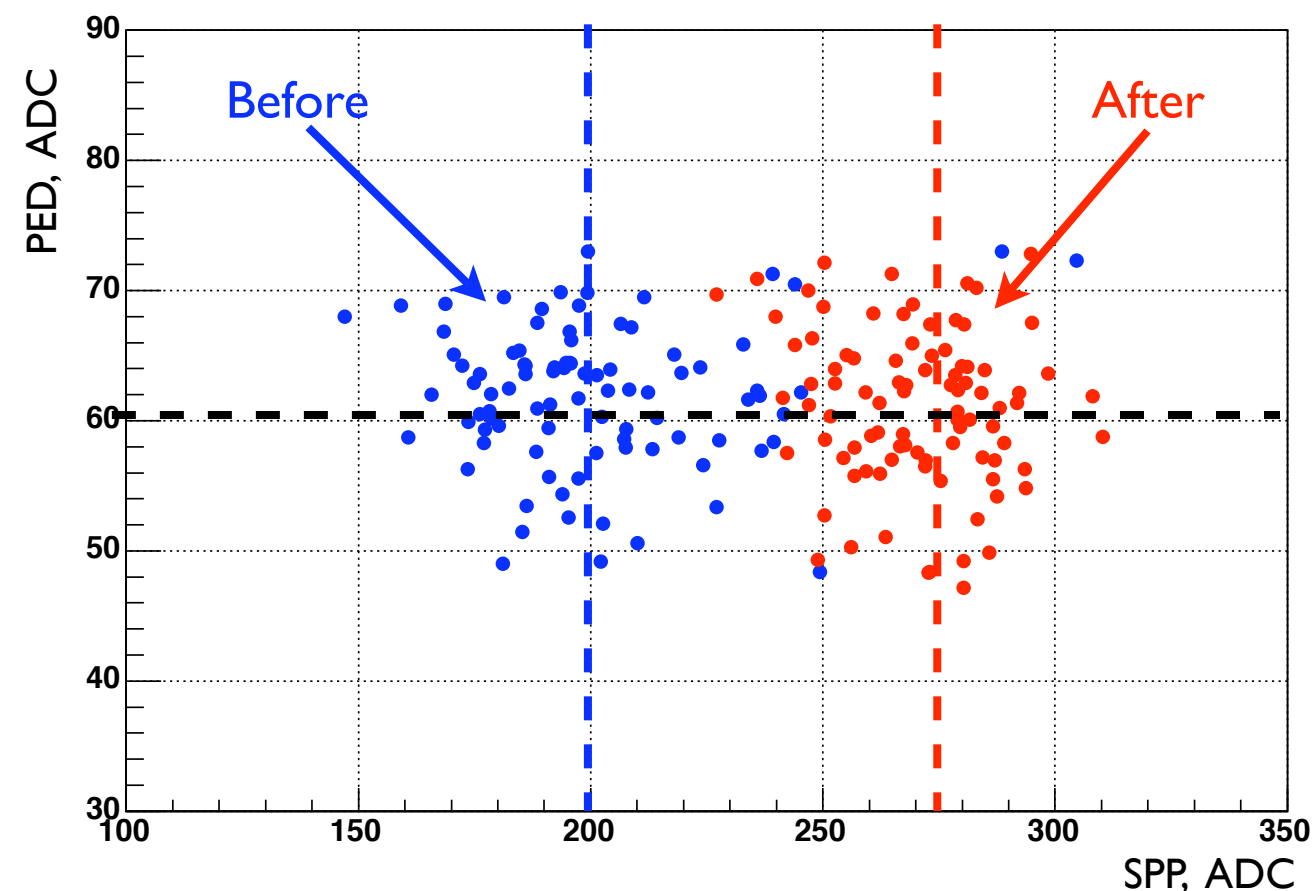
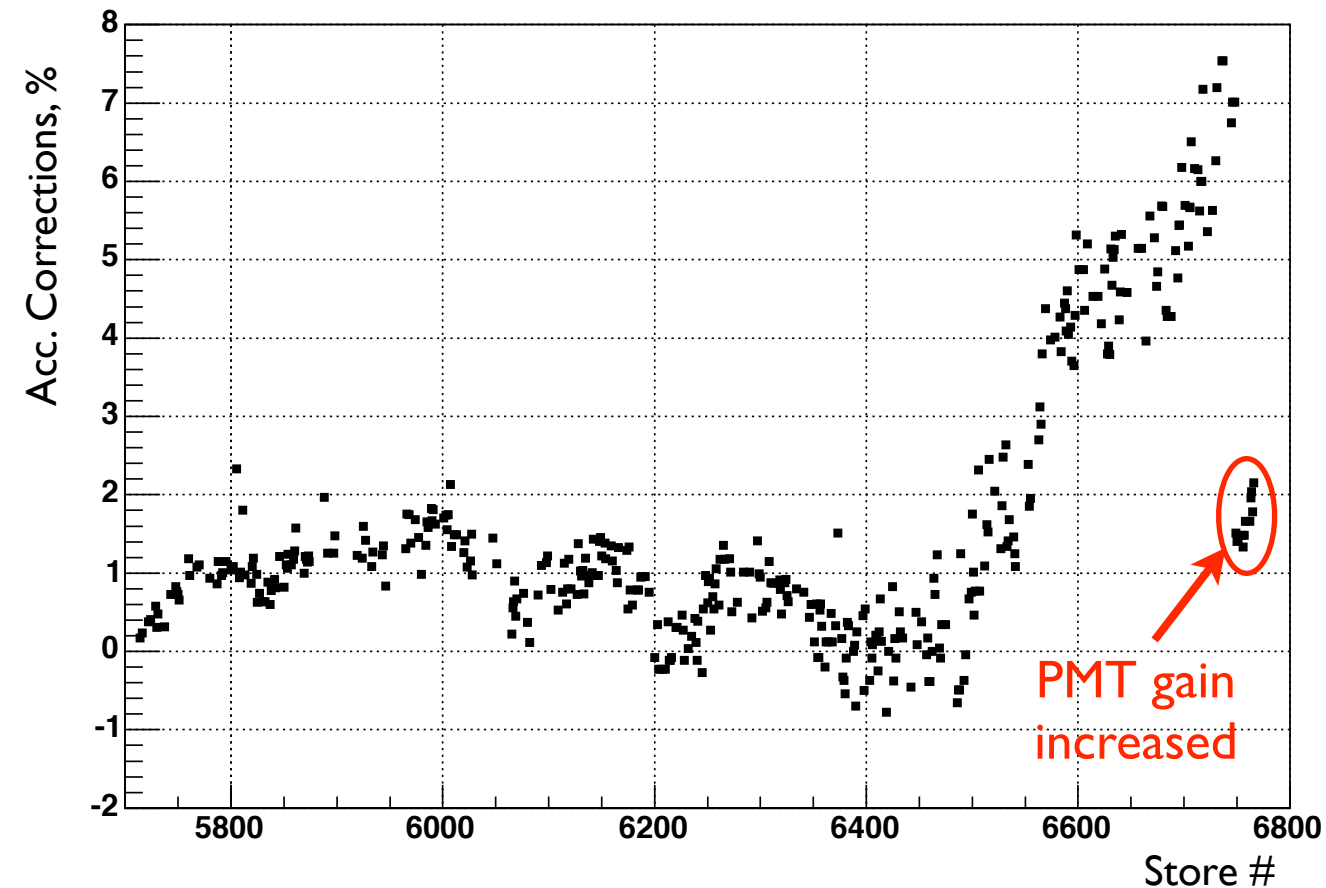
Easily fixed by offline corrections



Recent Pedestal Effect on Luminosity Measurement

- After October 2008 shutdown gain of our PMTs reached critical region and we begun gradually underestimate acceptance due to pedestal shift effect
- It is directly translated into Luminosity overestimation
- Increased PMT gain beginning Store 6749: reduced pedestal effect to 1.5-2%
 - ▶ We will use real pedestal values for *online* acceptances calculation: further eliminates these 1.5-2%

**Pedestal effect is easily taken into account by offline corrections:
Physics will not be affected**



Summary

- CDF Cherenkov Luminosity Counters is robust, capable instrument for precise luminosity measurements at Tevatron
 - ▶ *in situ* calibration from data allows to correct for various instability effects on store by store basis
- CLC performance is great at luminosities up to $400 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ with uncertainty of 4.5% [\oplus 4% from σ_{in} uncertainty, 6% total uncertainty]
- Longevity is not an issue: with PMT replacement / gain adjustment it will stay in operation until end of Run II
- Will continue excellent contribution to Physics results from CDF